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Assessing the role of human ear in sex identification among adult Egyptians: Anthropometric and Radiologic study

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ABSTRACT

Introduction: Human ear has gained popularity in the field of identification and despite its medico-legal role; it is still underestimated as a probable tool for sex determination. Few, if any, studies have been conducted on Egyptian population to assess its role in identification.
Aim of the work: To assess sex from the human ear (auricle and semicircular canals), to derive special equations for sex assignment in Egyptians.
Subjects and Methods: The study sample composed of 260 adult Egyptians divided into two groups. First, the external ear group (100 males and 100 females) where ear length, width and index, base of auricle, lobular length, width and index, lobule ear index and conchal length, width and index were taken for the left auricle. Second, the inner ear group (30 males and 30 females) who were subjected for radiological investigations by Multi- Detector Computed Tomography scanning of the petrous part of temporal bone. The measurement of the maximum height and width of the left three semicircular canals were taken and the index of each canal was calculated.
Results: Regarding the external ear; ear length and width, base of auricle, lobular width and index, and conchal length and width were significantly higher in males while lobule ear index was significantly higher in females. The sex classification accuracy was 80% with the significant parameters incorporated in one regression model. While for the inner ear all parameters were sexually dimorphic except for superior semicircular canal width which was insignificant between both sexes. The sex determination accuracy by logistic regression of all significant parameters reached 95%.
Conclusions: Measurements of both auricle and semicircular canals dimensions may be useful in sex determination when other methods are inconclusive. The inner ear parameters showed higher degree of expected accuracy.
Kew word: Sex, identification, external ear, semicircular canals, MDCT.

INTRODUCTION

Developing a biological profile has been a matter of interest for forensic experts and anthropologists. (1) It is fundamental in cases of mass disasters whether natural or man-made, where dismembered corpses, burnt bodies, purified corpses and skeletonized material are left (2, 3).

In forensic context, one of the prime tasks of forensic anthropologists is to assist in ascertaining the identity of human remains through the estimation of age, determination of sex, stature, and race. This estimation will result in the reduction of matching tests needed for further definitive confirmative tools such as DNA. The methods used to estimate the biological profile were developed through comparative studies of known skeletal populations (4, 5).

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Sex is one of the main tasks of forensic investigations and archaeological research. Correct sex assignment immediately eliminates about half of the population from the process of identification and enables the analysis of other sex dependent elements (e.g., age and stature). (5) The Visual (morphoscopic) and the morphometric techniques have been the traditional methods most commonly applied in the field of forensic anthropology. The visual assessment is the quickest and easiest method; the determination of sex is done by visual examination of appropriate elements of the skeleton and scoring a list of sex distinguishing features. The morphometric methods involve measuring between points on a structure, it is considered more advantageous in terms of objectivity, repeatability, and have more influence in court. (6, 7)

The ear represents a significant challenge for forensic researchers as it is the most crucial feature of the face. The individualistic and in-depth features of the ear as well as its anthroposcopic traits convey valuable information about sex and age, making the reconstruction feasible. (8)

Anatomically the human ear is divided into three distinguishable compartments: external, middle and internal parts. The external ear consists of the expanded part named the auricle (pinna), and the external auditory canal. It is separated from the middle ear by the tympanic membrane. (9)

The auricle is a highly complex structure composed of yellow elastic fibrocartilage covered by thin layer of skin, the shape of the cartilage gives the peculiar shape of the auricle unique for each person. The topographic landmarks, the dimensions and the bilateral position of the auricles are imperative for producing the distinguishing look of the human ear. (10, 11)

The middle ear inhabits the petrous portion of the temporal bone, the hardest and densest bone part in the mammalian body. It houses three tiny ossicles (malleus, incus and stapes). (12)

The inner ear consists of two functioning units; the bony labyrinth which is a series of interconnected cavities in the petrous part of temporal bone, and the membranous labyrinth which is formed of interlinked membranous sacs and ducts lying within the bony labyrinth. (13)

The bony labyrinth consists of the vestibule, semicircular canals and cochlea where the bone in this area is denser and harder than that of the other parts of petrous bone. The three semicircular canals; lateral, posterior and superior, each one is positioned perpendicular to the two other canals. (13)

In the last few decades, the field of forensic radiology has undergone rapid expansion; implementation of modern imaging technologies in forensic practice has been adopted in many countries. (14) Post mortem radiology “Virtopsy” is now becoming alternative to the traditional autopsy. Multidetector computed tomography (MDCT) scanning allows imaging of the whole corpse even inside the coffin and evaluates anatomic areas that are difficult to dissect. Moreover, it is ideal for depicting almost every anatomical and pathological structure with a high resolution and quality. (15, 16)

There is plethora of researches pertaining to a variety of populations, declaring that the ear can be used for sex assignment. (17-21) The present study was planned to explore the sexual dimorphism concerning various external ear measurements and that of inner ear structures obtained from the reformatted images of Multidetector Computed Tomography (MDCT), and to formulate regression equations capable of classifying sex with an accepted degree of accuracy.

SUBJECTS AND METHODS

Subjects:

The study was conducted up on 260 adult Egyptians aged 18 years old or more (130 males and 130 females) of both sexes. All subjects were randomly chosen and those with congenital anomalies of auricle or inner ear, ear disease, or tumor, history of previous ear surgery, craniofacial and head trauma and those belonging to other races or countries were excluded.

The participants were divided into two groups: First group (external ear group) was composed of 200 subjects of both sexes(100 males and 100 females) and the Second group (inner ear group) was composed of 60 subjects of both sexes (30 males and 30 females) who were referred to the Radio Diagnosis Department at Alexandria Main University Hospital for radiological investigations by Multi- detector Computed Tomography (MDCT) scanning of the petrous part of temporal bone as part of their clinical workup.

An ethical approval was obtained from the Ethics Committee of Alexandria Faculty of Medicine on the study and informed consent was taken from all subjects before participation in the present study.

Methods

The following data were taken from each group:

First group (external ear group):

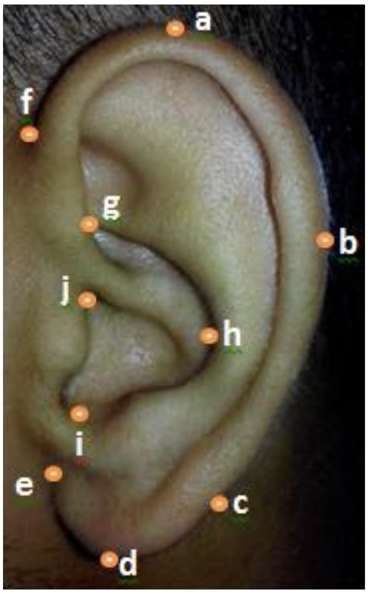
Various parameters related to the different anatomical landmarks of the auricle of the left ear (Fig. 1) were measured directly on the subjects with digital Vernier caliper (UNIOR Digital vernier - 270A, SOShanger). The participants were asked to sit in the Frankfurt plane (Natural head position looking straightforward with the lower borders of the eye sockets in same horizontal plane as the external auditory meatuses). [22]

The measured anthropometric parameters were:

1. Ear length (a-d): the straight line connecting the highest point on the free margin of auricle (super-aurale) and lowest point on the free margin of the ear lobe (sub-aurale). [18] (Fig-1).
2. Ear width (f-b): the straight line connecting the most anterior point of the ear located just in front of the helix (pre-aurale) and the most posterior point of the ear (post-aurale). [18] (Fig-2).
3. Base of auricle (f-e): the straight distance between pre-aurale and inferior most attachment of pinna. [18] (Fig-3)

4. Lobular length (i-d): the straight line connecting the deepest point on the intertragic notch (incisura intertragica inferior) and sub-aurale. [20] (Fig. 2)
5. Lobular width (e-c): the distance between the inferior most attachment of pinna (anterior lobule) and the posterior lobule at the midpoint of lobular length. [20] (Fig. 2)
6. Conchal length (g-i): the straight line connecting the concha superior and the incisura intertragica inferior. [23] (Fig. 3)
7. Conchal width (j-h): straight line connecting the most posterior point on the edge of the incisura anterior auris and the maximum concavity of the antihelix (i.e. the strongest antihelical curvature). [23] (Fig. 3)

Figure-1. Anatomical landmarks for auricular measurements



:

(a) Super-aurale: highest point on the free margin of auricle.
(b) Post-aurale: the most posterior point of the ear.
(c) Posterior lobule
(d) Sub-aurale: lowest point on the free margin of the ear lobe.
(e) Anterior lobule: inferior most attachment of pinna,
(f) Pre-aurale: the most anterior point of the ear located just in front of the helix
(g) Concha superior.
(h) Strongest anithelical curvature.
(i) Incisura intertragica inferior: the deepest point on the intertragic notch.
(j) Most posterior point on the edge of incisura anterior auris.

Four indices were calculated from the measured parameters

1. Ear index: it was calculated by using the formula: ear width/ ear length×100. [18]
2. Lobular index: it was calculated using the formula: lobular width/ lobular length × 100. [20]
3. Lobule ear index: it was calculated using the formula: lobular length/ear length × 100. [20]

Conchal index: it was calculated by using the formula: conchal width/ conchal length×100. [23]

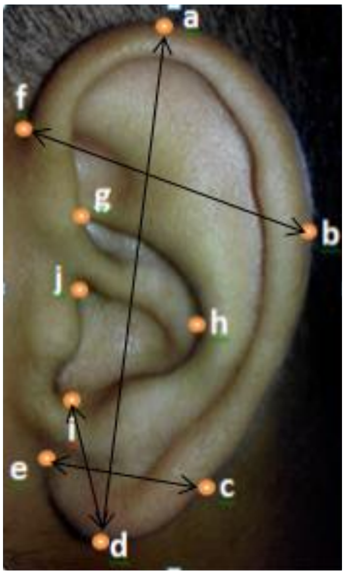


Figure-2.
Ear length: a-d
Ear width: f-b
Lobular length: i-d
Lobular width: e-c

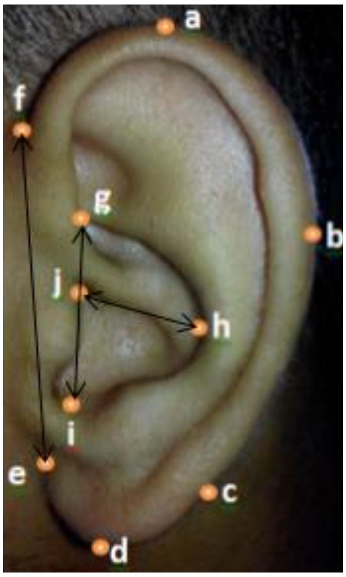


Figure-3.
Base of auricle: f-e
Conchal length: g-i
Conchal width: j-h

Second group (inner ear group):

Sixty subjects were CT scanned with 64 slices volume MDCT scanner (Siemens SOMATOM perspective). The CT series of the petrous part of temporal bone were recorded with slice thickness of 0.6 mm, using a tube current of 25 mA, tube voltage of 130 kV, pitch of 0.9, rotation time of one second and with reconstruction interval of 0.3 mm then the images were transferred to iMAC and multiplanar reconstruction was done using osirix dicom viewer.

After that projecting each semicircular canal of the left inner ear by double oblique reconstruction where the lateral canal is best projected in the axial plane, the superior canal in the oblique sagittal plane (Poschl) and the posterior canal in the coronal oblique plane (Stenver) then minIP reconstructions were used to delineate the canals. [24]

Then the maximum height and width of each canal were measured where the height was taken from the midpoint of the vestibule to the midpoint of the most projecting part of the canal while width was measured perpendicular to height. [25]

The following data were obtained: [25]
Lateral semicircular canal (LScc):
1. Maximum height (LScch). (Fig. 4a)
2. Maximum width (LSccw). (Fig. 4b)
3. Shape index: was calculated by using the formula: height/width (LScci).

Posterior semicircular canal (PScc):
4. Maximum height (PScch). (Fig. 5a)
5. Maximum width (PSccw). (Fig. 5b)
6. Shape index: was calculated by using the formula: height/width (PScci).

Superior semicircular canal (SSC):
7. Maximum height (SScch). (Fig. 6a)
8. Maximum width (SSccw). (Fig. 6b)
9. Shape index: was calculated by using the formula: height/width (SScci).

In both groups, measurements were taken in cm and in the inner ear group converted into mm for easier statistical analysis. In the study, measurements were taken by the same investigator twice during 2 different periods and the average values were calculated for further analysis.

Statistical analysis of the data [26, 27]

Data were fed to the computer and analyzed using IBM SPSS software package version 20.0. Qualitative data were described using number and percent. Quantitative data were described using range (minimum and maximum), mean, and standard deviation. Significance of the obtained results was judged at the 5% level.

The used tests were Chi-square test for categorical variables, to compare between different groups, Monte Carlo correction for chi-square when more than 20% of the cells have expected count less than 5, Student t-test, accuracy which is Rate of Agreement = (True positives + True negatives) / Total tested x 100 and logistic Regression to formulate the equations of sex determination.

RESULTS

First group (External ear group)

Age and sex distribution of the studied subjects of the first group are shown in table-1. In males, age ranged from 21 to 75 years with a mean age of 38.44 ± 14.37

Figure 4: CT scan of petrous part of temporal bone, axial plane.
a. lateral semicircular canal height
b. lateral semicircular canal width

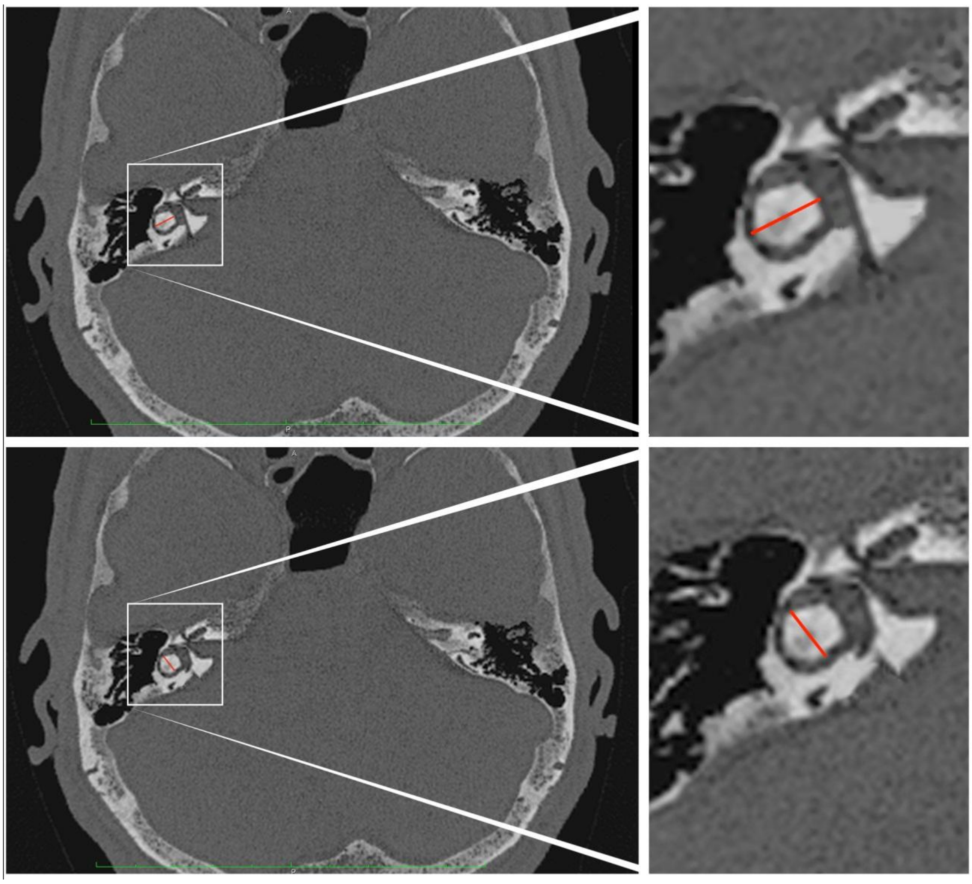


Figure 5: CT scan of petrous part of temporal bone, coronal oblique (Stenver) plane.

a. posterior semicircular canal height
b. posterior semicircular canal width

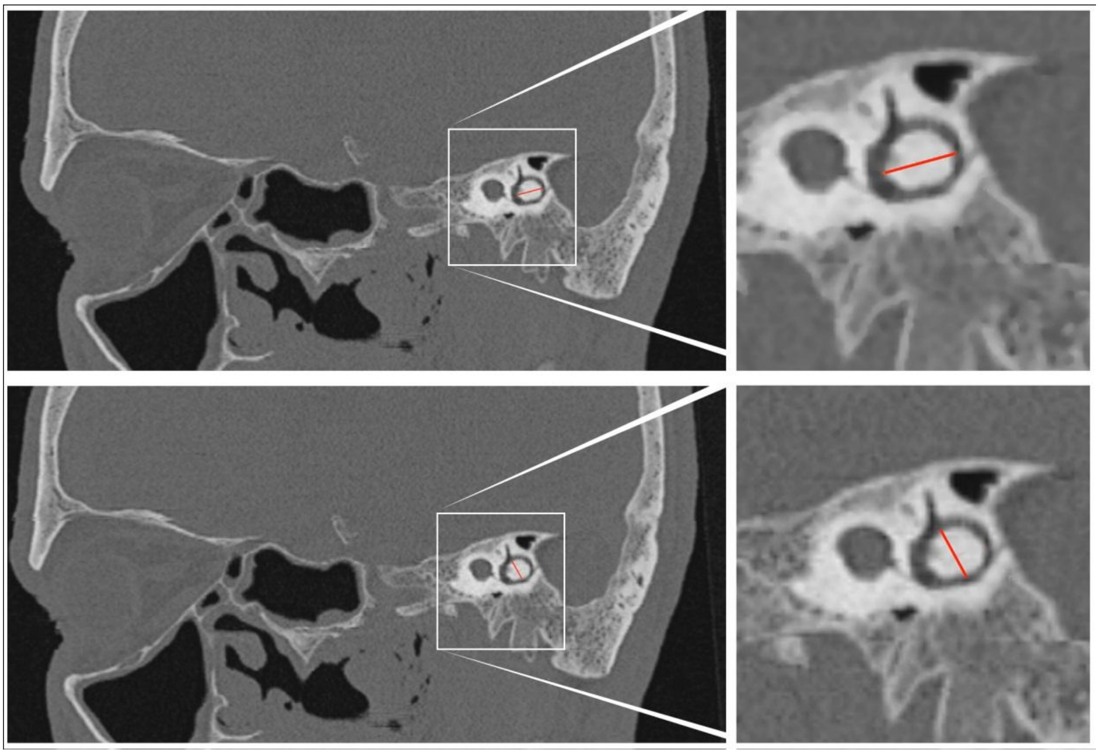


Figure 6: CT scan of petrous part of temporal bone, oblique sagittal (Poschl) plane.

a. superior semicircular canal height
b. superior semicircular canal width

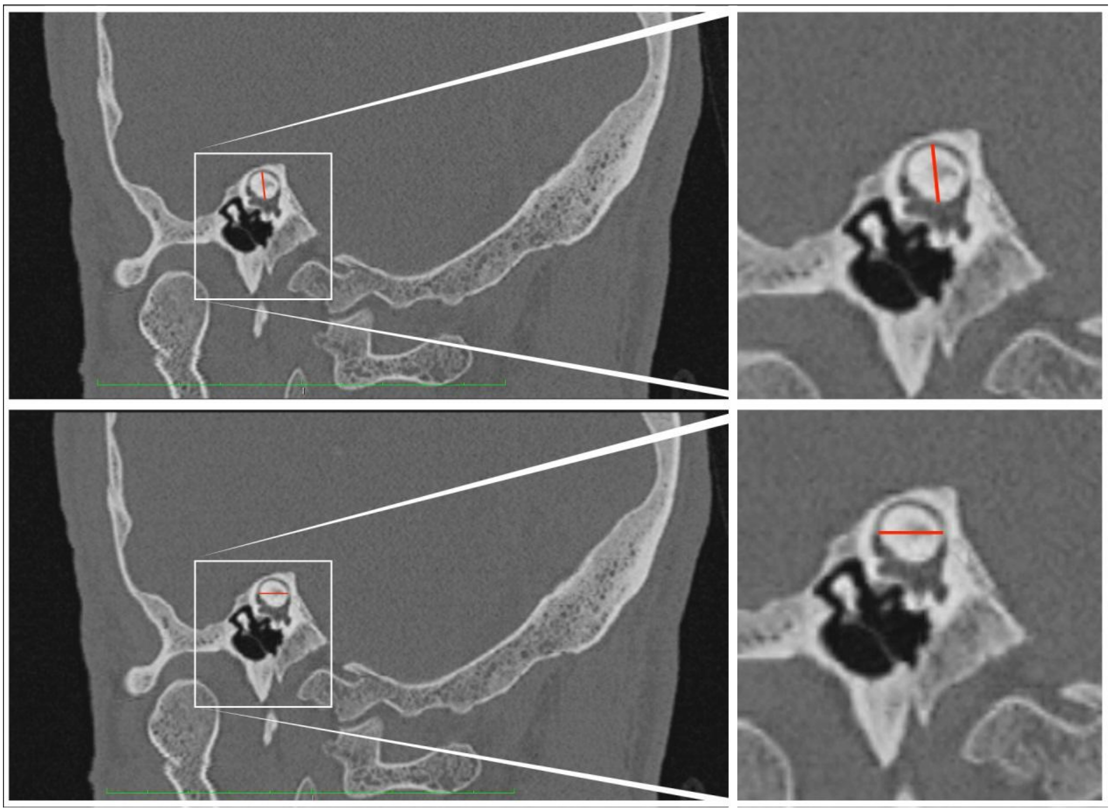


Table-1. Distribution of the first group subjects by age and sex. (n=200)

	sex				Total (n=200)	
	Male (n=100)		Female (n=100)			
	No.	%	No.	%	No.	%
Age						
18<30	33	33.0	26	26.0	59	29.5
30 -	27	27.0	27	27.0	54	27.0
40 -	13	13.0	41	41.0	54	27.0
50 -	16	16.0	6	6.0	22	11.0
60+	11	11.0	0	0.0	11	5.5
Min. – Max.	21.0 – 75.0		18.0 – 51.0		18.0 – 75.0	
Mean ± SD.	38.44 ± 14.37		36.69 ± 9.12		37.56 ± 12.04	
Median	33.50		38.0		37.0	
t (p)	1.025 (0.307)					

Min: Minimum; Max: Maximum; standard deviation; Student t-test ; *significance at p ≤ 0.05

Table-2. Descriptive analysis of the studied external ear parameters according to sex of subjects in the first group

Variable	Sex	N	Mean ± SD.	95% Confidence interval for mean		Minimum	Maximum	t(p)
				Lower bound	Upper bound			
Ear length	M	100	66.56 ± 5.11	65.55	67.58	48.43	79.58	4.127(<0.001*)
	F	100	63.76 ± 4.47	62.87	64.65	54.28	75.07	
	Total	200	65.16 ± 4.99	64.47	65.86	48.43	79.58	
Ear width	M	100	36.86 ± 2.95	36.27	37.44	24.28	42.76	4.498(<0.001*)
	F	100	34.95 ± 3.05	34.34	35.55	28.68	52.37	
	Total	200	35.90 ± 3.14	35.46	36.34	24.28	52.37	
Ear index	M	100	55.55 ± 4.72	54.61	56.49	37.02	75.18	0.782(0.435)
	F	100	54.99 ± 5.37	53.93	56.06	45.09	86.28	
	Total	200	55.27 ± 5.05	54.57	55.98	37.02	86.28	
Base of auricle	M	100	52.23 ± 5.73	51.10	53.37	39.54	68.46	7.594(<0.001*)
	F	100	46.62 ± 4.67	45.69	47.55	34.69	62.34	
	Total	200	49.43 ± 5.92	48.60	50.25	34.69	68.46	
Lobular length	M	100	19.81 ± 3.15	19.18	20.43	13.68	29.73	1.091(0.277)
	F	100	20.27 ± 2.79	19.71	20.82	14.78	27.94	
	Total	200	20.04 ± 2.98	19.62	20.45	13.68	29.73	
Lobular width	M	100	22.72 ± 2.69	22.18	23.25	15.76	29.39	1.991(0.048*)
	F	100	21.89 ± 3.16	21.26	22.52	14.82	29.92	
	Total	200	22.30 ± 2.96	21.89	22.72	14.82	29.92	
Lobular index	M	100	116.63 ±17.65	113.13	120.13	72.59	164.60	3.047(0.003*)
	F	100	109.19 ±16.86	105.85	112.54	65.78	150.16	
	Total	200	112.91 ±17.61	110.46	115.37	65.78	164.60	
Lobule ear index	M	100	29.73 ± 3.94	28.95	30.51	20.42	44.13	3.928(<0.001*)
	F	100	31.73 ± 3.23	31.09	32.37	24.77	38.42	
	Total	200	30.73± 3.73	30.21	31.25	20.42	44.13	
Conchal length	M	100	26.83 ± 3.11	26.21	27.44	15.53	41.15	3.299(0.001*)
	F	100	25.53 ± 2.40	25.06	26.01	20.79	33.43	
	Total	200	26.18 ± 2.84	25.79	26.58	15.53	41.15	
Conchal width	M	100	18.67 ± 2.43	18.19	19.15	12.04	25.33	3.570(<0.001*)
	F	100	17.50 ± 2.19	17.06	17.93	12.91	22.40	
	Total	200	18.08 ± 2.38	17.75	18.41	12.04	25.33	
Conchal index	M	100	70.26± 10.67	68.14	72.38	36.12	117.0	0.710(0.478)
	F	100	69.17± 11.06	66.97	71.36	48.27	96.01	
	Total	200	69.71± 10.86	68.20	71.23	36.12	117.0	

t, p: t and p values for Student t-test ; *: Statistically significant at p ≤ 0.05

Table-3. Regression equations for sex determination from the studied external ear parameters

	Equation	Cutoff	Adjusted R^2	Accuracy
Ear length	-8.075+(Ear length*0.124)	-0.058	63.0	65%
Ear width	-8.258+(Ear width*0.230)	-0.157	65.0	68.5%
Base of auricle	-9.938+(Base of auricle*0.202)	-0.191	71.0	73%
Lobular width	-2.161+(Lobular width *0.097)	-0.302	56.0	56.5%
Lobular index	-2.847+(Lobular index *0.025)	-0.413	58.0	59%
Lobule ear index	4.833+(Lobule ear index *-0.157)	0.0021	64.0	63.5%
Conchal length	-4.732+(Conchal length *0.181)	-0.134	61.5	66.5%
Conchal width	-3.976+(Conchal width *0.220)	-0.029	62.0	63%
All significant parameters	-32.989 + (Ear length *0.115) + (Ear width *0.150) + (Base of auricle *0.221) + (Lobular width*-0.299) + (Lobular index*0.102) + (Conchal length*-0.066) + (Conchal width *0.117) + (Lobule ear index *0.133)	-0.4858	76.5	80%

Sex is male when the result of equation is more than the cut off value
Sex is female when the result of equation is less than or equals to the cut off value

Table-4. Distribution of the second group subjects by age and sex (n=60)

	Sex				Total (n=60)	
	Male (n=30)		Female (n=30)			
	No.	%	No.	%	No.	%
Age						
<30	8	26.7	14	46.7	22	36.7
30 -	12	40.0	8	26.7	20	33.3
40 -	7	23.3	3	10.0	10	16.7
50 -	3	10.0	5	16.7	8	13.3
Min. – Max.	18.0 – 58.0		18.0 – 61.0		18.0 – 61.0	
Mean ± SD.	35.40 ± 10.02		33.07 ± 12.40		34.23 ± 11.24	
Median	33.50		31.50		32.0	
t (p)	0.802 (0.426)					

t, p: t and p values for Student t-test

years with a mean age of 36.69 ± 9.12 years. There were no statistical significant differences between males and females regarding the age (P=0.307).

Table-2 shows the descriptive analysis of the measured external ear parameters according to sex. Ear length and width, base of auricle, lobular width, lobular index, and conchal length and width were significantly higher in males than in females while lobule ear index was significantly higher in females than in males. On the other hand, ear index, lobular length and conchal index reveal non-significant difference between both sexes.

For sex determination, logistic regression equations were obtained first using each significant parameter separately then combining all the significant parameters in one equation where the studied measurements were the independent variables and sex was the dependent one Table-3.

The highest accuracy (73%) was obtained by using the base of auricle followed by ear width (68.5%) and conchal length (66.5%). The accuracy increased to 80% when all significant parameters were used in one equation.

Second group (Inner ear group)

Table-5 shows the age distribution of male and female patients of the second group. In males, the age ranged from 18 to 58 years with a mean age of 35.40 ± 10.02 years. In females, it ranged from 18 to 61 years with a mean age of 33.07 ± 12.40 years. There was no significant difference as regard age between both sexes, where p = 0.426.

The descriptive statistics of the measured radiological parameters according to sex was illustrated in Table (6) Sexual dimorphism by Student's t-test was applied to each variable where all parameters showed statistically significant difference between both sexes being higher in males except for superior semicircular canal width which was insignificant between males and females. Table (6)

Table-5. Descriptive analysis of the studied radiological parameters according to sex of subjects in the second group

Variable	Sex	N	Mean ± SD.	95% Confidence interval for mean Lower bound	Upper bound	Minimum	Maximum	t(p)
Lateral scc height	M	30	5.45 ± 0.31	5.33	5.57	5.14	6.43	6.810(<0.001*)
	F	30	4.97 ± 0.23	4.88	5.05	4.52	5.33	
	Total	60	5.21	5.11	5.30	4.52	6.43	
Lateral scc width	M	30	6.50 ± 0.44	6.34	6.66	5.71	7.34	3.332(0.002*)
	F	30	6.14 ± 0.40	5.99	6.29	5.49	7.09	
	Total	60	6.32	6.20	6.44	5.49	7.34	
lateral scc Index	M	30	0.84 ± 0.06	0.82	0.86	0.75	0.98	4.060(<0.001*)
	F	30	0.81 ± 0.05	0.79	0.83	0.73	0.92	
	Total	60	0.83	0.81	0.84	0.73	0.98	
Posterior scc height	M	30	7.0 ± 0.57	6.79	7.21	5.44	8.11	3.588(0.001*)
	F	30	6.48 ± 0.41	6.33	6.64	5.78	7.39	
	Total	60	6.74	6.60	6.89	5.44	8.11	
Posterior scc width	M	30	7.09 ± 0.51	6.90	7.28	5.93	8.13	6.656(<0.001*)
	F	30	6.68 ± 0.35	6.55	6.81	6.07	7.45	
	Total	60	6.88	6.76	7.01	5.93	8.13	
Posterior scc Index	M	30	0.99 ± 0.07	0.96	1.01	0.85	1.17	4.429(<0.001*)
	F	30	0.97 ± 0.05	0.95	0.99	0.87	1.09	
	Total	60	0.98	0.96	1.0	0.85	1.17	
Superior scc height	M	30	7.01 ± 0.44	6.85	7.17	6.20	8.20	2.104(0.040*)
	F	30	6.36 ± 0.31	6.25	6.48	5.84	6.94	
	Total	60	6.69	6.56	6.81	5.84	8.20	
Superior scc width	M	30	7.84 ± 0.54	7.64	8.05	6.74	8.79	1.084(0.283)
	F	30	7.35 ± 0.30	7.24	7.46	6.83	7.97	
	Total	60	7.60	7.47	7.72	6.74	8.79	
Superior scc Index	M	30	0.90 ± 0.06	0.87	0.92	0.76	1.0	2.381(0.021*)
	F	30	0.87 ± 0.04	0.85	0.88	0.75	0.93	
	Total	60	0.88	0.87	0.89	0.75	1.0	

Scc: semicircular canal; t, p: t and p values for Student t-test ; *: Statistically significant at p ≤ 0.05

Table-6. Regression equations for sex determination using the studied radiological parameters of the three semicircular canals of the inner ear

	Equation	Cutoff	Adjusted R^2	Accuracy
Lateral scc height	-65.607+(12.635* Lateral scc height)	-0.7894	0.695	85%
Lateral scc width	-12.949+(2.050* Lateral scc width)	-0.321	0.211	71.7%
lateral scc Index	-8.345+(10.104* lateral scc Index)	-0.2618	0.095	58.3%
Posterior scc height	-14.347+(2.128* Posterior scc height)	0.5277	0.291	76.7%
Posterior scc width	-14.628+(2.127* Posterior scc width)	0.4099	0.239	75%
Superior scc height	-33.699+(5.064* Superior scc height)	-0.4285	0.585	81.7%
Superior scc width	-20.454+(2.704* Superior scc width)	-0.0929	0.335	71.7%
Superior scc Index	-12.033+(13.663*Superior scc Index)	0.4003	0.120	58.3%
All significant parameters	-328.042+ (Lateral scc height* 25.423) + (Lateral scc width* -1.158) + (Posterior scc height* 2.202) + (Posterior scc width* -4.675) + (Superior scc height* -20.435) + (Superior scc width* 25.941) + (lateral scc Index* -30.998) + (Superior scc Index* 211.450)	-1.0648	0.879	= 95%

Scc: semicircular canal; Sex is male when the result of equation is more than the cut off value ; Sex is female when the result of equation is less than or equals to the cut off value.

Nine significant logistic regression equations were obtained for sex determination. Table (7) shows eight equations using each significant parameter alone and the ninth equation uses all of the significant parameters in one equation. Accuracy was calculated for each equation and it was showed that lateral, superior and posterior semicircular canal heights were the highest (85%, 81.7% and 76.7%, respectively). While with the overall equation accuracy increases to 95%.

DISCUSSION

Identification has always been an important and very challenging aspect in forensic cases especially if only human remains are present. (28) Both identification and creating a biological profile are necessary in forensic anthropology casework where sex determination is a main step for estimating a reliable profile. (29)

The ear is a characterizing highlight of the face; its different structures give data about sex. (30) The petrous part of the temporal bone is one of the most robust and dense structures present in the human skeleton. It is very likely the best-preserved part of the available fragments of the skeleton from a crime scene or archaeological site to the extent that it can be identifiable in human cremated remains thus sexing this bone is important. (31, 32)

Moreover, the fact that this structure is very impervious to cruel taphonomic conditions and being completely developed before birth makes it a reasonable target for the development of sex determination method which is age-independent. (25)

The present study was conducted on adult Egyptians to assess the role of various auricular and inner ear parameters in sex determination in a sample of Egyptian population.

In the present study digital vernier caliper and CT were used to measure the auricular and inner ear parameters respectively. The digital Vernier is considered to be an easy, efficient tool for taking anthropometric measurements with high accuracy and precision with no need for another measuring instrument as a ruler or tape measure. Nowadays CT scan is considered the most reliable radiological technique for assessing bone morphometry. (28)

In both groups, measurements were taken twice in order to ascertain accuracy and by the same investigator in order to diminish bias and mistake of identification of the different landmarks of the auricle or the semicircular canals.

Regarding the external ear, the current study revealed that ear length was significantly higher in males than in females which was in agreement with almost all studies conducted in different countries and on various populations irrespective of race, ethnicity, environmental, genetic or socio-cultural factors.(18-21, 33-35) Even in other studies which didn't apply statistical tests to assess significance, ear length was found to be higher in males. (30, 36, 37)

However only Eboh study (2013) on Nigerians (22) showed that ear length was insignificant between both sexes and the combined measurements from both right and left ears was higher in females. This could be attributed to the point that they included both children and adult Nigerian subjects aged from 6 years up to 60 years in their study. That was unlike the rest of studies who all included only adult subjects.

The present study showed that males have significantly larger ear width when compared with females and this was consistent with previous reports of Sadacharan on Indian Americans (2016) (19), Ahmed and Omer (2015) in their study on Sudanese (20), Taura et al (2013) on Nigerians (34) and Deopa et al on Indians (2013) (35), but differ from Eboh study (2013) on Nigerians (22) in which ear width was non-significant between both sexes although higher in males.

The measurement of base of auricle in the present study was significantly higher in males than in females. This was comparable to Murgod V. et al study on the Indians. (18)

The lobular length in the existing study was statistically non-significant between both sexes although higher in females and that was similar to the Murgod V. et al study. (18) On the other hand, the higher values in Nigerian females in Eboh study (22) was significant which could be due to the traditional and cultural habit of wearing heavy earrings that could have caused elongation of the ear lobule.

However, in contrast to the present study, lobular length was higher in males in several studies on Sudanese (20), Turkish people (30), Pakistani population (21), Indians (35, 37) and Nigerians. (36)

The difference from the present study could be due to racial and ethnic differences and could be affected by genetic, nutritional and environmental factors all of which could affect the ear structure.

The measurements of lobular length and width in Brucker et al (33) study of external ear morphometry on American males were found to be nearly identical to females.

In the current study, it was observed that lobular width was significantly larger in males than in females and that was in accordance with previous studies. (20, 21, 35) In addition, lobular width was higher in males than in females but without assessing the significance statistically in both Bozkır et al study on Turkish (30) and Arora1 L and Singh V study on Indians. (37)

On the contrary the two Nigerian studies by Eboh (22) and Ekanem et al (36) showed that lobular width was not significantly higher in females. This could be attributed to racial differences.

The conchal length and width in the present study were significantly higher in males and that was congruent with the Sudanese. (20) In the study carried out by Arora and Singh, both parameters were also higher in Indian males than females but they didn't check the significance of their results statistically regarding its relation to sex. (37)

On the other hand, and in contrast to the current work Wang et al (2011) study on Chinese reported that

conchal width was insignificant between males and females. This difference from the present study could be attributed to racial difference or to different methodology where they assess the auricular anthropometry using Computed tomography. (38)

The ear index was non-significant in the present study between both sexes and this has also been reported previously among Sudanese (20) and Indians. (18, 35) However, on the contrary, ear index showed statistically significant sexual dimorphism in both Sadacharan study (2016) on Indian Americans (19) and Taura et al (2013) on Nigerians (34) where Taura et al followed a different methodology in which they used calibrated transparent ruler to take the measurement and this could be the cause of their different results.

The current study revealed that the lobular index was significantly higher in males and that was consistent with Ahmed and Omer study (20) but differs from the study conducted by Deopa et al (35) who reported that ear index was non-significant between both Indian sexes. In the existing work, female had significantly larger lobule ear index while the conchal index was statistically insignificant between males and females and that was in agreement with the Sudanese population. (20)

The current study revealed that the predictive accuracy of the significant external ear parameters using logistic regression analysis for assigning sex ranged from 56.5% to 73% when each parameter was used alone with the highest accuracy occurred with base of auricle while the lobular width showed the least accuracy.

The results of the current work showed that the maximum sex determination accuracy occurred when all the sexually dimorphic parameters were incorporated in the same regression model where the accuracy reached 80%.

These accuracies are near to that of other studies in different population where the sex classification accuracy reported by Ahmed and Omer (2015) of the arab Sudanese ranged between 60.5% and 72% being 71% for the left ear when using multiple direct discriminant functions. (20) while the predictive sex identification accuracy of the Indians ranged from 68–71% using discriminant function analysis in the study conducted by Murgod et al (2013).(18)

The accuracy of Egyptian sex determination from ear parameters was close to that from the length of hand bones which was measured using two dimensional images of multidetector computed tomography where their accuracy was 76% for proximal phalanges and 80 % for each of distal phalanges and metacarpals. (39)

Regarding Inner ear group, the present work revealed that the height of the three semicircular canals and the width of lateral and posterior semicircular canals showed statistical significant difference between males and females being higher in males and this was in agreement with Osipov et al study (2013) on exhumed Greek individuals. (25)

Only the width of the superior semicircular canal in the current study showed insignificant differences between both sexes and that was in the contrary to Osipov et al (25) study on the Greek who found that the mean width of superior canal demonstrated significant sexual dimorphism. Also they found that only lateral canal index was significantly different between both sexes while both the posterior and superior canals indices were statistically insignificant and that was different from the present study in which the three indices of the three semicircular canals were sexually dimorphic indicating that both sizes and morphological shapes of the canals were statistically significant between Egyptian males and females.

These differences between the current study and Osipov et al study could be attributed to the fact that their study was on exhumed remains while the present work was on living individuals, also the technique used for measurements; where Osipov et al used 3D reconstructions of both right and left labyrinths and the mean reading was considered unlike the present work which utilized 2D reconstructions of only left labyrinth.

The sex estimation accuracy of the inner ear parameters in the present study ranged from 58.3% to 85% when applying logistic regression analysis to each significant parameter where the lateral canal height was found to give the highest accuracy unlike Osipov et al study (25) who reported that the posterior canal measurements gave the highest accuracy when univariate discriminant function analysis was applied.

The accuracies by univariate discriminant function analysis of the height and width of the posterior canal in Osipov et al study both were found to be 74% while in the present study they were 76.67% and 75% respectively.

In the current work, the predictive sex classification accuracy improved considerably when all the significant parameters were incorporated in one regression model where it reached 95% while in Osipov et al study on the Greek, the cross-validated accuracy reached 82% when multivariate equations were used up on combinations of canal heights, widths, and indices.

The sex determination accuracy of the Egyptian population using inner ear parameters in the present study was higher relative to other anatomical parts in the skull. It was higher than the overall accuracy of maxillary sinus (69.9%) (40) and of frontal sinus (67%) (41) by multiple regression equations. Also it was higher than piriform aperture where the accuracy by using stepwise discriminant function analysis was 75.4% and furthermore the accuracy was higher than that of mastoid process measurements which reached 80% by multiple discriminant function analysis. (42,43, 44)

CONCLUSION

From the current study, it could be concluded that anthropometric measurements of the auricle (using digital Vernier caliper) is a useful technique for sex determination among Egyptians when other methods are inconclusive. The base of auricle was the single parameter with the highest accuracy (73%) and the accuracy increased to 80% when the sexually dimorphic parameters were incorporated in the same regression

model. However, the semicircular canals dimensions (using MDCT) were found to classify sex with a higher degree of accuracy that reached 95% by using the significant semicircular canals measurements in one equation.

Recommendations:

- It is recommended to conduct further studies on a larger number of subjects especially for the inner ear group in order to confirm the results of the present work.
- Further researches are recommended to study the effect of age related changes on different ear parameters as well as the sexual differences of ear parameters in younger subjects.

Limitation

The limitations of the present study were the relatively small study sample especially of the inner ear group and that age-related changes on auricular morphometric parameters were not studied among the participants.

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Conflict of Interests

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